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DETECTION EFFICIENCY OF Ge(Li) and HPGe
DETECTORS FOR γ -RAYS UP TO 10 MeV*

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ABSTRACT

We have calibrated the relative efficiency up to 9.7 MeV for two coaxial detectors, one Ge(Li) and one high purity Ge. The efficiency curves were determined by using a combination of standard radioactive sources and (n, γ) reactions. Based on the result of this work, the general slope of the two detector efficiency curves appears to be similar and in agreement with earlier work reported by McCallum and Coote. When plotted as a semilogarithmic function of energy the efficiency is linear from 2 to 9.7 MeV.

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I. Introduction

The use of high resolution Ge(Li) or high purity Ge detectors (HPGe) for nuclear spectroscopy requires a determination of detector efficiency and energy calibration. In general, standard radioactive multigamma-ray sources emitting conveniently spaced photopeaks with well known energies and relative intensities have been used¹. Standard sources such as ^{182}Ta , ^{56}Co , ^{133}Ba , $^{110\text{m}}\text{Ag}$ and ^{226}Ra have been commonly used in nuclear counting laboratories for those purposes over various energy regions. The technique of using several sources with overlapping energy ranges extends the detector efficiency and energy calibration. Unfortunately the energy region calibrated with this technique is usually limited to an energy less than 3.5 MeV. A ^{56}Co source² is the only long-lived source which will provide photopeaks up to 3.5 MeV. Above that no convenient standard source is currently available for both energy and efficiency calibration. The efficiency calibration of Ge(Li) detectors has been studied by many authors^{3,4,5}. McCallum and Coote⁶ reported on detector relative efficiency studies up to 11 MeV. They found that the efficiency curve of a Ge(Li) detector decreased rather rapidly above 4 MeV compared to a linear extrapolation on a log-log plot of efficiency versus energy. Our studies of the decay of the fission product ^{84}As ($Q_{\beta} \approx 10$ MeV), using the automated fast chemistry facility⁷ at Lawrence Livermore Laboratory (LLL), have revealed intense gamma rays up to 9 MeV. In order to determine the gamma ray abundances, we have had to re-examine the shape of efficiency curves up to approximately 10 MeV for both the Ge(Li) and the high purity Ge detectors used in our measurements. Information on beta strength functions of many nuclei far from the stability, especially the neutron rich nuclei, are largely deduced from the study of gamma rays. Consequently the determination of the efficiency curve of a

gamma ray detector at high energy is an important component in both gamma-ray and beta-decay studies.

II. Methodology

The absolute efficiency of a Ge(Li) detector has been determined with an accuracy of approximately 2% using several standard multigamma-ray sources⁵. This high accuracy calibration is presently limited to energies less than 2 MeV. With the ⁵⁶Co available, efficiency calibration could be extended up to 3.5 MeV. In this work we have re-examined the efficiency curves of a Ge(Li) and a HPGe coaxial detector by using a combination of standard multigamma ray sources¹ such as ¹³³Ba, ^{110m}Ag, and ⁵⁶Co have been used to cover the energy range up to 3.5 MeV for both detectors. The thermal neutron capture on targets of stable chromium isotopes and ³⁵Cl were used for producing gamma rays up to approximately 10 MeV. The thermal neutron reactions for both targets have relatively high capture cross sections (σ_c (⁵³Cr) = 18 b; σ_c (³⁵Cl) = 43 b) and produce prominent gamma rays of well known energies and intensities^{8,9} which are well spaced over a wide energy range. Therefore, they are highly suitable for determinations of detector efficiency. In addition both targets are easily accessible and have physical properties that are tractable. The common neutron capture standard, ¹⁴N⁸, is also a potential source for high energy calibration, but was not used in this calibration because of its relatively low thermal neutron cross section. Relative intensities of high energy gamma rays such as ⁵³Cr (n, γ) ⁵⁴Cr and ¹⁴N (n, γ) ¹⁵N reactions were first determined using relative efficiency curves deduced from known intensity balance of certain single cascades from (p, γ) resonances⁶.

The lack of consistent, reliable efficiency standards at high energy has caused many measurements of relative and absolute thermal-capture-gamma-ray intensity to be in error by more than 10%¹⁰. With experimental improvements the errors of relative intensity for gamma rays in the $^{35}\text{Cl} (n,\gamma) ^{36}\text{Cl}$ reaction have been reduced to a value which is comparable to the lines of ^{15}N ($\approx 5\%$). For this work, we have combined both standard multi-gamma-ray sources and capture gamma-ray sources to determine the detector efficiency curve by normalizing strong low energy photopeaks in the capture gamma ray sources to the curve determined from radioactive standards. If the absolute intensity of standard gamma ray source is known, the absolute efficiency of the detector can also be determined at high energy.

III. Equipment and Detectors

An external beam of thermal neutrons with a flux of approximately 10^9 n/cm²/sec were obtained from the Livermore Pool Type Reactor. Targets of natural abundance chromium metal or CCl₄ sealed inside a pyrex tube were placed separately in the neutron flux at a distance of 32 cm from the lead shielded gamma ray detector. Liquid nitrogen cooled ORTEC coaxial detectors (one Ge(Li) and one high purity Ge), both with an efficiency of approximately 13% and a resolution of approximately 2 keV at 1.332 MeV were placed at an angle of 90° to the neutron beam. Standard nuclear spectroscopy equipment including a Canberra 80 series multichannel analyzer was used. A standard Pb X-ray absorber consisting of Cu and Cd foils surrounded the detector during the measurements. Area extraction of gamma ray peaks was done by the available programs in the analyzer.

IV. Results

In Fig. 1 we present the efficiency curves for both detectors that result

from our work using a combination of standard multigamma-ray sources and capture gamma rays. The top curve in Fig. 1 is for the high purity Ge detector while the bottom curve is for the Ge(Li) detector. Both curves deviate rather rapidly from the straight line extrapolation on the log-log graph. At approximately 10 MeV, the measured curve has dropped approximately a factor of 2 below a straight line extrapolation. For the energy region between 300 keV and 3 MeV, the curve appears to be a straight line. The dotted lines indicate the linear extrapolations for the purpose of comparisons with the measured efficiency curves. Based on direct comparison between these curves, they are similar in shape and in agreement with the work of McCallum and Coote⁶.

Table 1 gives the coefficients of 5th and 6th order polynomials obtained from an unweighted computer fitting of the data points for two different energy regions. The equation of relative efficiency is given in the form of $\ln \epsilon_i = \sum_{j=1,6} a_j (\ln E_i)^{j-1}$, where E_i represents the energy in units of keV and a_j are coefficients given in the table. Both equations are plotted as smooth curves in Fig. 1.

When plotted on a semilogarithmic plot, the efficiency curve for both detectors appears to be linear from 2 to 10 MeV. From the practical point of view, extension of the efficiency curve based on a straight line extrapolation on a semilogarithmic plot would be a workable method for obtaining an approximate efficiency curve at high energy, even without using thermal neutron capture gamma rays. Since the slope of the curves for these two detectors is slightly different at high energy, it would become more reliable to have at least one independent calibration point at high energy. A possible calibration point is the gamma ray at an energy of 6.129 MeV that occurs in

the deexcitations of ^{160}Gd . It can be produced by the reaction of ^{13}C (α, n) ^{160}Gd , as the result of population at the level of 6.129 MeV in ^{160}Gd . A combination source such as $^{244}\text{Cm} + ^{13}\text{C}$ can be made and absolutely calibrated¹². Hence a secondary standard gamma-ray source for establishment of the high energy portion of both energy and efficiency calibration is possible.

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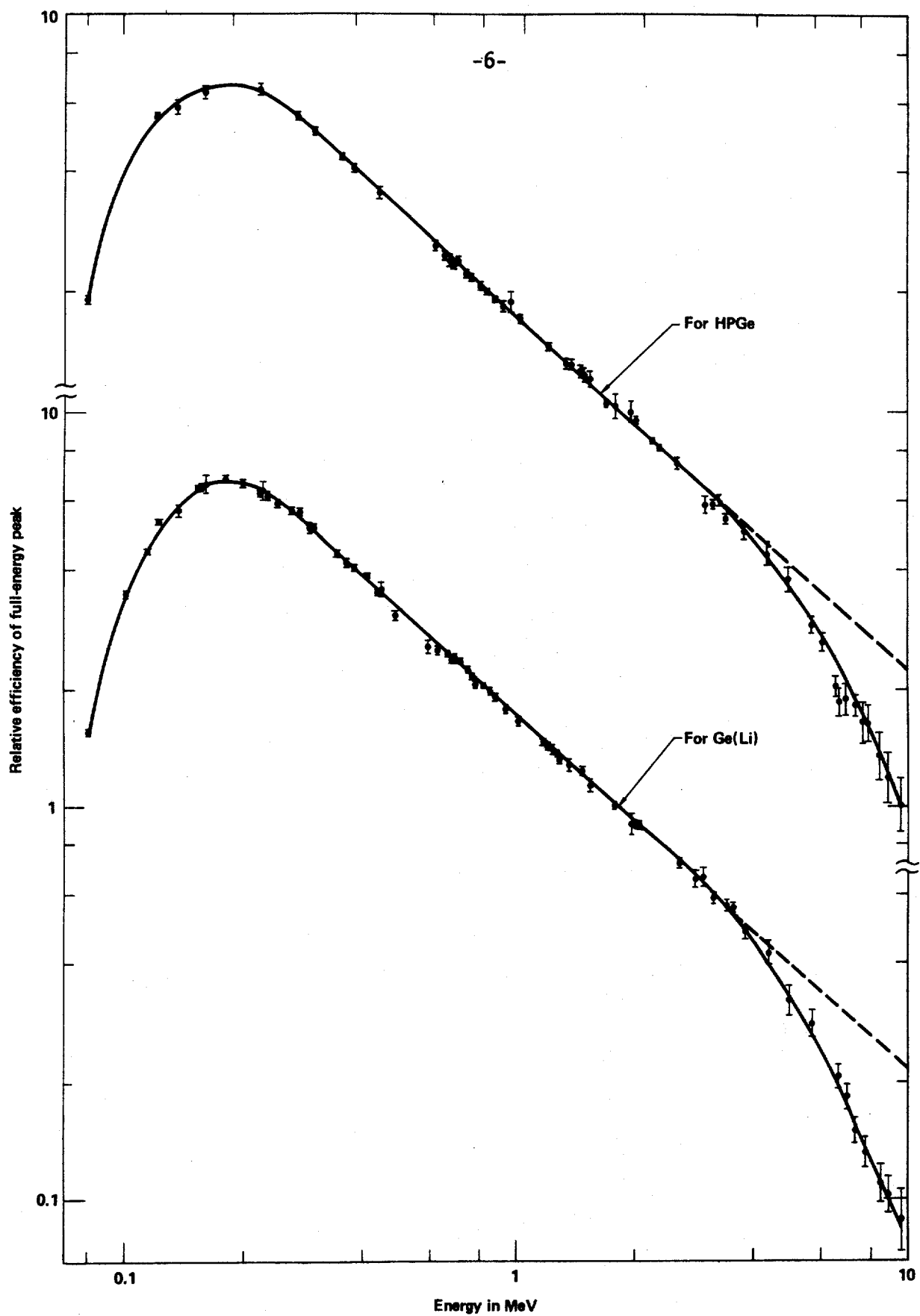


Fig. 1. Relative efficiency curves. The upper curve is for the HPGe detector and the bottom one is for the Ge(Li) detector. Both detectors with x-ray absorbers were placed at 32 cm to the target.

TABLE 1

COEFFICIENTS OF POLYNOMIALS FOR RELATIVE EFFICIENCY CURVES

$$\ln \epsilon_i = \sum_{j=1,6} a_j (\ln E_i)^{j-1}$$

	HPGe with x-ray absorber		Ge(Li) with x-ray absorber	
	80 1,000 (keV)	700 10,000 (keV)	80 1,000 (keV)	700 10,000 (keV)
a ₁	5.583484 x 10 ⁻¹	5.554820 x 10 ⁻¹	5.454347 x 10 ⁻¹	5.425167 x 10 ⁻¹
a ₂	-8.143926 x 10 ⁻¹	-8.513116 x 10 ⁻¹	-8.200305 x 10 ⁻¹	-9.039662 x 10 ⁻¹
a ₃	-4.716715 x 10 ⁻²	-4.417474 x 10 ⁻²	-8.378286 x 10 ⁻²	1.493954 x 10 ⁻²
a ₄	-2.651750 x 10 ⁻¹	-3.969594 x 10 ⁻²	-3.384564 x 10 ⁻¹	2.451231 x 10 ⁻¹
a ₅	-1.457360 x 10 ⁻¹	2.453228 x 10 ⁻²	-1.741303 x 10 ⁻¹	-2.886225 x 10 ⁻¹
a ₆	0	-1.497862 x 10 ⁻²	0	6.229418 x 10 ⁻²

